Carbon capture and storage

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CARBON CAPTURE AND STORAGE: MAKING FOSSIL FUELS GREAT AGAIN?

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At present, Carbon Capture and Storage, in which CO_2 is captured from flue gasses and stored in geological formations, is one of the technologies to reduce CO_2 emissions associated with the use of fossil fuels. Are there some good arguments to continue to invest in fossil fuels, a technology of yesterday?

▲The world's ever-expanding CO_2 emissions (credit: Luke Robus and Emmet Norris)

The best way to sequester carbon is to leave all fossil fuels in the ground. A simple solution, and as the price of renewables has dropped significantly, a solution that seems to be almost within reach. However, globally, last year more CO_2 was emitted in the atmosphere than ever before (Fig. 1), which suggests that we have many years to go before our energy production is completely renewable. In the meantime, storage of CO_2 in geological formations seems attractive. The technology of Carbon Capture and Storage (CCS) involves three steps: the capture of CO_2 from flue gasses, the compression and transport of CO_2, and the injection in geological formations [1][2]. The different technologies that are used in each of those steps are not new, as in a different context they are routinely used in our current economy.

Carbon Capture

Carbon capture technology is based on the natural gas sweetening process and uses amine solutions to capture the CO_2 [3]. This technology can be easily adopted to separate CO_2 from flue gasses. However, the amine-based capture technology is not cheap. Given the volumes of flue gasses, capture plants must be enormous and require a capital investment of about the same amount as the one for the original power plant. In addition, once the CO_2 is captured in the amine solution, the solution must be regenerated by removing the CO_2, which requires the redirecting of steam from the power plant. This steam loss together with the work required for the subsequent CO_2 compression can give a loss of efficiency of a power plant of about 30%. Therefore, reducing the costs of the capture process is the main driver for the research in that field. Hence, research has been mainly focused on finding better amine solutions and improvements in the process. However, because of the oxygen content in the flue gas by which amines tend to oxidise and thermal degradation, the amines must be replaced over time and clean-up of the waste stream is necessary. Therefore, there are considerable research efforts to develop alternative technologies to amine-based ones [4]. These include different separation technologies such as membranes, solid adsorbents, or chemical looping.

CO_2 transport and injection in geological formations

Transport and injection of CO_2 in geological formations is routinely carried out for enhanced oil recovery. The fact that the major oil companies know how to transport and inject CO_2 in geological formations makes CCS ready to be employed on a very short timescale. The idea to use geologically sequestered CO_2 to even produce more fossil fuels does not sound like a sensible solution to reduce CO_2 emissions. At present there are some projects that use the more expensive, anthropogenic CO_2 in which CO_2 is injected in such a way that a maximum amount of CO_2 remains in the oil production field. In such projects the CO_2 emissions per unit oil is (slightly) less than oil production without enhanced oil recovery [5]. But more importantly, this is one of the few CCS-related technologies that are economically viable without a carbon tax or other regulation to limit CO_2 emissions. Therefore, the fact that the use of CO_2 in enhanced oil recovery offsets the costs makes the process one of the few large-scale demonstration projects to further develop the technology. Alternatively, research is also being carried out into the feasibility to sequester CO_2 in the oceans [6].

Pilot projects for CO_2 injection

In addition to enhanced oil recovery, there are a few pilot and demonstration projects in which CO_2 is injected in geological formations for the sole purpose of permanently sequester the CO_2. The projects have been successful from a technical perspective, yet the public perception of CO_2 storage in geologic formations is focused on the perceived risks. Therefore, most of the research related to geological storage focusses on obtaining such a high level of understanding of the behaviour of CO_2 injected in these geological formations that we can guarantee that the CO_2 is permanently sequestered. Elementary thermodynamics tells us that CO_2 is not the most stable form of carbon; over time the carbon in CO_2 ends up in carbonate minerals such as limestone ($CaCO_3$). Therefore, eventually the injected CO_2 will be converted to different carbonate forms, but this takes place over time scales of more than tens of thousands of years [7]. These pilot and demonstration projects provide essential data to validate the predictions of the long-term behaviour of the injected CO_2. Unfortunately, most of the large-scale injection field projects, which were so essential to further build the confidence of the public in the long-term CO_2 storage, have been put on hold or delayed.

CO_2 utilisation

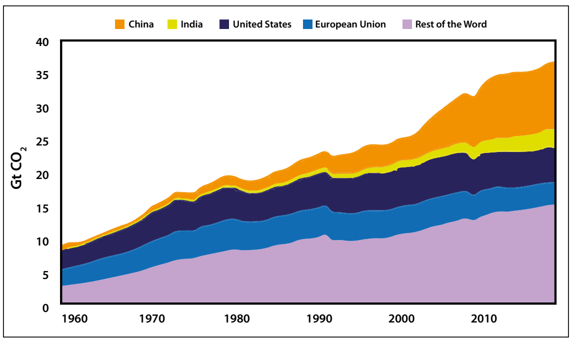
One can often hear the argument, why do we sequester the CO_2 in geological formations? Would it not make much more sense to recycle the CO_2? Here, we have a problem of scale. The amount of CO_2 we produce by power generation is gigantic. If we would compare it with the top 50 of all chemicals produced by the chemical industry, CO_2 would be number one, with a production 10 times larger than this top 50 combined! [8]. We simply produce too much CO_2 that if we would convert it into the most beautiful and used product one could imagine, it would simply saturate any conceivable market. One can envision to convert the CO_2 back into a fuel. Indeed, there are days in which there is an excess of solar energy and converting CO_2 into a fuel is one of the many ways to store energy. However, if the source of the CO_2 is the burning of fossil fuels one has to be careful. One can recycle CO_2 as many times as one likes, but eventually this CO_2 molecule needs to be sequestered; for every fossil fuel carbon atom we take out of the ground we need to put one CO_2 molecule back, otherwise it will eventually end up in the atmosphere.

Direct Air Capture of CO_2

As 40% of the emitted CO_2 will stay 500-1000 years in the atmosphere, CO_2 emissions have much more in common with nuclear waste than we might think; once generated we have to live with the consequences for a very long time. This long lifetime of CO_2 in the atmosphere combined with our inaction to address CO_2 emissions makes it most likely that we will overshoot the CO_2 levels associated with the 1.5 and 2 °C increase in global temperatures. If this happens, the only option we have is to reduce CO_2 levels by capturing CO_2 directly from the air [9]. Basic thermodynamics tells us that the lower the CO_2 concentration the more energy is required for the capture process. Hence, if CCS already looks expensive, allowing CO_2 molecules to escape in the atmosphere and worrying about it later, can be an even more expensive solution.

Outlook

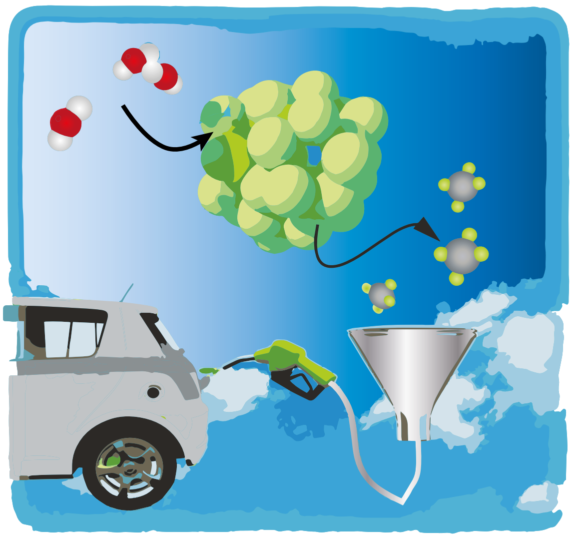
We will have to accept the fact that there will be a price on carbon which will be so high that we need to find solutions for any source of carbon. Even if power generation



◂ **FIG 1:** Global CO_2 emissions per country (Source: IEA World Energy Balances 2019, https://www.iea.org/data-and-statistics) is completely decarbonised, there are still many sources of CO_2. This implies that we will have to replace fossil fuels as the source of carbon by CO_2 for the chemical industry [10]. This can be done by capturing CO_2 from, for example, waste incineration or the production of biogas. We also need to capture the CO_2 from many industrial sources, including the production of cement and steel. We need to ensure that fossil fuels are replaced by synthetic fuels by capturing CO_2 from the air or any other source [11] (Fig. 2), and converting it to fuels. All these require a complete rethinking of the chemical industry. In such a world, there are many small and large local sources of CO_2 and many routes to convert CO_2. The research we are carrying out in this vision towards achieving zero anthropogenic CO_2 emissions, is to find novel materials that are tailor-made for all possible different types of CO_2 emitting processes. Our research [12] combines state of the art computational methods in which we screen millions of possible materials for which we predict the performance before a material is even synthesized [13]. The ranking of these materials will depend on a performance metric, which is related to an optimal process design for a given source and target of CO_2.

Conclusions

We can all agree that the best way to permanently sequester carbon is to leave all fossil fuels in the ground, but we also have to face the fact that there are large uncertainties when or even if this will happen. The urgency to reduce CO_2 emissions now cannot not be stressed enough. One may need to be pragmatic, energy is a too important factor in our economy to be ignored. The fossil fuel industry is still the major player. Large-scale carbon capture combined with geological storage is a viable technology that allows us to significantly reduce CO_2 levels. From a scientific point of view, providing a solution that does not remove the root cause of the problem is not great. That will be difficult to accept for those who feel one should not invest in technologies we should be moving away from. One does need to keep in mind that reducing CO_2 levels is the most important challenge of our generation, and making the fossil fuel industry part of the solution goes against all logic. However, the argument is not about logic but about the urgent need to do something now, and for that we need all the help we can get.



▸ **FIG 2:** A sustainable way to replace fossil fuels is to capture CO_2 from the air and by using renewable energy to convert it into synthetic fuels using an efficient catalyst (figure adopted from Tan and Maroto-Valer).

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